APRIL, 1923 BULLETIN, 384

NEW JERSEY
AGRICULTURAL EXPERIMENT STATIONS

LATE BLIGHT OF POTATOES AND THE WEATHER

WM. H. MARTIN

NEW BRUNSWICK
NEW JERSEY

NEW JERSEY AGRICULTURAL EXPERIMENT STATIONS*

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Late Blight of Potatoes and the Weather

Wm. H. Martin, Ph.D., *Plant Pathologist*

Late blight of the potato, caused by the fungus, *Phytophthora infestans* is probably the most serious of the many diseases of this important agricultural crop. Some idea of the losses resulting from this disease may be obtained from the reports of the Plant Disease Survey of the Bureau of Plant Industry, U. S. Department of Agriculture. In these it is estimated that in 1918 late blight reduced the potato crop in the United States by 8,745,000 bushels; in 1919, 20,978,000 bushels; in 1920, 43,257,000 bushels; and in 1921, 2,106,000 bushels. During the past four years the losses from late blight in New Jersey have not been particularly severe, yet there have been years when, in some sections of the state, a total crop loss was experienced. This was particularly true in 1889 and 1897; in these years there was such an abundance of rot that in many instances no attempt was made to dig the crop in South Jersey.

In view of the economic importance of late blight, numerous investigations have been conducted to throw some light on the life history of the causal organism and to obtain some information concerning the relation between its occurrence and the weather. As the result of carefully performed laboratory tests by various workers and of field observations by others, it is established that epiphytotics of late blight are dependent to a considerable extent on the existence of favorable meteorological conditions.

As early as 1888 Scribner (20) stated that "the years of serious outbreaks of late blight have always been years of excessive humidity and that a temperature of from 65° to 75° F. produces conditions favorable for the disease." "The rapid spread of late blight," according to Galloway (5) "is dependent in a large measure upon certain conditions of moisture and heat. A daily mean or normal temperature of from 72° to 74° for any considerable time, accompanied by moist weather, furnishes the best conditions for the spread of the disease."

Orton (18) as a result of his observations in Pennsylvania is of the opinion that precipitation alone has little, if any, bearing in determining an outbreak of late blight, nor has atmospheric temperature alone or when correlated with precipitation. He believes that the most important contributing factors are high relative humidity and low soil temperatures. His observations are not in accord with those of Halsted (6) who, as a result of his correlation of late blight and weather in New Jersey, states that, "late blight seems to be quite dependent upon an abundance of moisture in mid-summer," and further (7) "a second favoring condition is warm weather, not hot or cold, but a condition of the atmosphere which obtains when there is a week or month of showery weather, often spoken of as close or "muggy."

Lutman (13) has assembled observations made in Vermont covering

a period of twenty years in which he shows that a very rainy season is likely to be accompanied by an epidemic of late blight. He points out, however, that while rainfall is undoubtedly the chief factor, it is limited in its effects by humidity, sunshine, temperature and also possibly by wind.

Jones (10) likewise presents data that clearly indicate the close relationship that exists between outbreaks of late blight and weather conditions. In 1891 he notes that "the temperature was low and the rainfall slight the last of July and the first of August. August 10, however, the weather became very warm and on the 12th and 14th was followed by a fall in temperature and copious rains, and this followed by another rise in temperature and more rains about the 21st. The conditions favoring the blight began thus about the 12th. The blight was first observed the 16th or 17th." In 1892, 1893, and again in 1895 conditions favorable for the development of the disease were experienced with results similar to those reported for 1891. In 1894 Jones writes that "July was warm but dry, and August was cool and dry to an extent unknown in the memory of the oldest inhabitant. These conditions proved so unfavorable to the fungus that no blight was seen upon the leaves during the growing season, a small amount of dry rot was found in the tubers upon digging them, thus showing that a very little of the fungus did occur." According to Jones (11) the conclusions are justified that "the late blight organism has probably been introduced with seed potatoes into practically all of the potato growing sections but that the disease does not develop unless the weather is moist and without too great heat."

Similar correlations made in Michigan by Coons (2) indicate that a cool, wet July followed by an August with moderate to heavy rainfall has always given epidemics of late blight in the lower Peninsula of Michigan. Erwin (4) has likewise correlated the appearance of late blight with weather conditions in Iowa and concludes that the climatic conditions under which late blight occurs in that state are a high degree of humidity with heavy dews and mid-summer temperatures lower than usual. An excess of rainfall and a predominance of cloudy weather are contributing factors.

In Ohio, Selby (21) states that with cyclar periods of low summer temperature, outbreaks of late blight for one or more seasons may be anticipated.

Morse (17) reports that in Maine it is a matter of common observation that an outbreak of late blight follows a period of wet weather during the months of July, August and September. McKay (14) finds that in Oregon the disease spreads rapidly under favorable warm and moist weather conditions while in Minnesota, Stakmen and Tolaas (23) state, "while the disease is probably present in the north-eastern part of the state in a mild form every year, it becomes serious only when periods of wet and probably cool weather occur during the latter half of the summer." Macoun (15) reports that the weather conditions which appear to favor the spread of late blight in Canada are what is known as "muggy" or close days with much moisture in the air. Duggar (3) expresses the view that the distribution of the fungus is dependent upon climatic conditions. According to him, it has been shown that late blight becomes of im-

portance only when favored by warm, moist weather. He states further, however, that while it is generally true that warm weather is required, it has been shown that the high temperature of summer quickly checks the spread of the disease. His observations are not in accord with those of Reed (19) who notes that the disease has not appeared in Virginia until the advent of weather cool enough to bring lower temperatures during the night. Reed states that late blight is seldom found in Virginia at altitudes below 2000 feet. Ward (24) likewise observes that late blight was observed during dull, cloudy, and wet weather, cooler than usual, when the temperature was saturated for days together in July and August. Clinton (1) states that in Connecticut "Rainy weather in July and August starts the fungus in the fields, and if there then comes a continuous period of rainy, cloudy or foggy weather the foliage will soon be defoliated. Wet weather in August or September following the blighting of the vines determines largely the amount of rot that develops in the tubers."

Among the investigators who have studied the thermal relations of the organism might be mentioned Jensen (9) who states that the late blight organism cannot exist where the mean temperature exceeds 25°C. (77°F.). Jones (11) as a result of his extensive studies with the late blight organism found that best growth results between 16° and 19°C. (60.8°-66.2°F.). Below 16°C. the growth was slower and below 5°C. (14.°F.) it was wholly inhibited. Growth was likewise inhibited at 23°C. (73.4°F.) and there was no sporulation above 25°C. (77°F.) and no vegetative growth at, or above 30°C. (86°F.). As the result of his infection studies of potato foliage with the organism causing late blight, Melhus (16) has shown that at low temperatures, 10-13°C. (50-55.40°F.) from 95 to 100 per cent of the leaves became infected in 4 to 6 days. At 17°C. (63°F.), 85 per cent showed infection and as the temperature increased above this point the infection percentage decreased until at 25-30°C. (77°-86°F.) there were few or no infections.

It is apparent from the above review of literature on the relation of late blight to the weather that the various workers are not in accord as to the temperature most favorable for the development of the disease; as Smith (22) points out, however, some of these tests refer to constant and others to mean daily temperature, likewise the temperature terms used by investigators in various parts of the country are relative. In the extreme northern sections of the country the mean summer temperature is too low for the best development of late blight and the central and southern districts are too warm. This accounts for the fact according to Smith, that in the northern states late blight is referred to as a warm weather disease while in the southern sections cool weather is said to favor its development. Smith expresses the view that probably the most favorable open air temperature conditions for the development of the disease is when the mean daily temperature is between 70° and 74°F. and that the disease is checked if the mean daily temperature is above 75°F. for a few days and that the spores are killed at a temperature of 77° to 80°F.

Late Blight in New Jersey

Late blight was first reported in New Jersey in 1889. In writing of the epidemic of that year Halsted (8) states that "growers throughout

whole sections of the country did not harvest their potatoes, while others dug and placed them in heaps, where they rotted." Since this first recorded appearance of late blight in the State, fairly complete records have been kept of its recurrence for every year with the exception of 1910 and 1911. In view of the recognized importance of data of this kind in advancing our knowledge concerning the cause of epidemics of plant diseases and particularly of the conditions likely to produce an epiphytotic of late blight the observations of the past thirty-four years have been brought together and an attempt made to correlate climatic conditions with the appearance of the disease.

Following is a summary of the observations made on the prevalence of late blight in New Jersey since 1889. Those from 1889 to 1909 were made by B. D. Halsted, from 1912 to 1921 by M. T. Cook and for 1922 by the writer. The records on the occurrence of the disease are taken from the Annual Reports of the New Jersey Experiment Stations for the year in question with the exception of those for the years 1901 and 1902 which were taken from the Climate and Crop Survey Bulletin published by the United States Department of Agriculture, in co-operation with the New Jersey Weather Service.

1889. "There was a phenomenal outbreak of the potato rot, and both the *Phytophthora infestans* D. By. and the bacterial disease, working alone or together, carried off the main portion of the crop. Large growers throughout whole sections of the country did not harvest their potatoes, while others dug and placed them in heaps, where they rotted.

1890. "This has been a year of trouble with the potato. In many parts of the state the crop has been large and profitable, in others abundant, but decays of various sorts have been destructive. In Salem and Cumberland counties for example, the growers perhaps, suffered most. In some fields tubers were dug, placed in heaps, and there remained a worthless, rotten mass. Other farmers were plowing the ground for wheat, paying no attention to the large crop of decayed potatoes in the soil. In short, the entire crop was rotted. The cause of this wholesale decay was in part, at least, due to the fungus *Phytophthora infestans,* De. By."

1891. "While not one-quarter as prevalent as last year, this rot has not been absent, especially among late potatoes. It was first observed in July, about ten days after a series of rains. The writer is more than ever convinced that much of the decay of Irish potatoes in the east is due to bacteria, and the Phytophthora gets credit for much more damage than is its due."

1892. "Late blight rot has not been absent, especially among the late potatoes. The writer is still more than last year inclined to the belief that much of the decay of Irish potatoes in the East is due to bacteria and black mould, and the Phytophthora gets credit for doing more damage than it its due."

1893. No late blight reported by Halsted.

1894. "Early blight important." No record of late blight.

1895. "Early blight was sufficiently abundant (at New Brunswick) to do considerable injury." No record of late blight.

1896. "Very little leaf blight of any sort was manifest upon the crop." (at New Brunswick). No record of late blight.

1897. "At New Brunswick late blight was found upon all three varieties of potatoes, namely, 'Early Rose,' Rural No. 2, and American Giant. The development of the fungus was more rapid upon the 'Rural' than upon the other two sorts, and, by watching the growth of the diseases from day to day it was evident that there may be varietal differences in potatoes that render some sorts more susceptible to the disease than others. The worst specimens of late blight were found upon plants that were grown under the lath shading, but they came after the plants in the open had turned brown—in other words, the shaded plants were attacked later than others." "The same potato sections were visited as in 1889 and the same story of destructive decay was listened to as related by the disappointed potato growers. The *Phytophthora infestans* was so abundant in some fields that scarcely a leaf escaped its attack."

1898. "Several correspondents for the Weather and Crop Bulletin report blight but in view of the fact that drought conditions were noted generally this trouble was probably not late blight."

1899. "Season remarkable for the small amount of fungus troubles."

1900. "The year has been comparatively free from complaints of those fungi that ravage the truck crops. No spraying was done with potatoes except to kill the enemies, it having been shown in previous years that this crop with us is not troubled seriously with diseases of the leaves."

1901. "The rotting of potatoes was reported in the Weather and Crop Bulletins by five correspondents on August 27, and by three on September 10."

1902. "The rotting of potatoes was reported by a number of correspondents to the Weather and Crop Bulletin. The number reporting and the dates on which the reports were made follow: July 29, Rot (1); Aug. 5, Blight (4) Rot (5); Aug. 12, Rot (4), Blight (1); Aug. 19, Rot (5); Aug. 26, Rot (5); Sept. 2, Rot (4); Sept. 9, Rot (3); Sept. 10, Rot (7). Similar reports in 1903 were investigated by Dr. Halsted who found the cause to be *Phytophthora infestans*. The rotting in 1902 was probably due to the same cause."

1903. "The rotting of potatoes was reported in the Weather and Crop Bulletins as early as August 4 and for weeks the number of reports of rot increased. On August 18 the correspondents reported as follows: "Potatoes are rotting badly," "Potatoes rotting in many fields," "Potato rot increasing in some places." For August 25 and September 1 the common expression was, "Potatoes are rotting badly." The potato is troubled with a number of plant diseases, all of which may have had some part in the wholesale decay above indicated. An examination of the fields, however, leads to the opinion that the chief trouble has been the so-called potato rot."

1904. "The Weather and Crop Bulletin correspondents report as follows: May 17, Rot (1); Aug. 9, Blight (3), Rot (3); Aug. 16, Rot (7), Blight (2); Aug. 22, Rot (5); Aug. 30, Rot (7); Sept. 6, Blight (2); Aug. 22, Rot (5); Aug. 30, Rot (7); Sept. 6, Rot (7); Sept. 13, Rot (8). The reports of rot, mildew and mold have been much less severe than during the previous season."

1905. One correspondent to the Weather and Crop Bulletin reports blight. In view of the fact, however, that this was a dry season and all other correspondents report drought injury, this was probably not late blight.

1906. "There has been fully an average amount of plant diseases during the year. Among truck crops, the lima beans were perhaps the most to suffer from a mildew, appearing in August, and being particularly destructive in some localities. The comparatively dry September proved very helpful to the potato growers, whose crop was prevented thereby from serious decay."

1907. "Among the plants in the ornamental and trial grounds the *Solanum commersonii,* beginning in September, showed a large amount of late blight (*Phytophthora infestans*) in all parts of the foliage and stems. A number of trial hills of United States Department of Agriculture novelties of the ordinary potatoes growing a short distance from the above relative, showed no signs of the disease." "Potatoes have had their rots and blights."

1908. "There have been less fungous diseases than usual upon most of the crop plants during the season of 1908." No record of late blight.

1909. "Not many diseases in the state."

1910. No record available.

1911. No record available.

1912. "One report of 'late blight.'"

1913. "The potato crop suffered greatly from a combination of weather conditions and diseases. The most important of these diseases were the southern bacterial wilt, scab, black leg, fusarium wilt and scurf." "Late blight was of very little importance."

1914. "Two records on seed potatoes in the spring. Very abundant in North Jersey in the fall."

1915. "This disease was more abundant on the growing crop than usual."

1916. "This disease was not reported but probably occurred in the mountainous districts."

1917. "This disease was not reported but probably occurred in the mountainous districts."

1918. "An outbreak throughout Mercer and Monmouth counties and the southern half of Middlesex but the losses were not serious."

1919. "In 1919 there was a severe outbreak throughout practically the entire state beginning the latter part of July and gradually becoming more and more severe throughout the growing season. The losses in the early or main crop were very slight but the losses in the late crop were very heavy. The losses during the last few days of July

and the early part of August were complicated by losses due to bacterial rot. Undoubtedly the greater part of the early losses were due to bacterial rot."

1920. "Severe on the commercial (early) crop in some sections of Monmouth and Mercer counties and on the late crop in the southern part of the state. This outbreak was not as destructive as that of 1919."

1921. Considerable tip burn and early blight with heavy infestation of plant lice. No late blight.

1922. Late blight was first observed June 23. It progressed rapidly so that by July 25 most of the fields in Monmouth County were severely blighted and it was found extensively in Mercer and Middlesex counties. Rot was severe in some localities but was not wide spread. In South Jersey there was only a trace of late blight on the late planted crop.

Influence of Rainfall on Late Blight

It will be seen from this summary of the observations on the occurrence of late blight in New Jersey that in the 34-year period the disease was present eighteen and absent fourteen years (1910 and 1911 not included), and that it was much more severe in some years than in others. It is shown later that the recorded differences in the severity of the disease are due largely to differences in weather conditions. In attempting to correlate the appearance of late blight with existing weather conditions it is impossible to designate any one factor as being the one most directly concerned. The results of our studies indicate that rainfall and temperature are probably the most important contributing factors, but it is recognized that their influence is augmented or limited by sunshine, humidity and possibly by winds and soil temperature. In view of the fact, however, that data on the three last mentioned factors are not available, this discussion is limited to a consideration of the influence of rainfall and temperature on late blight with a brief discussion of the influence of sunshine.

In table 1 is shown the precipitation records for the months of June, July, August and September for each year since 1889 and also a statement concerning the prevalence of late blight for the corresponding year. The rainfall records were taken from the United States Department of Agriculture Weather Bureau, Climatological Data, New Jersey Section and represent the mean rainfall for the state. The mean rainfall was used because in many instances the records of the occurrence of late blight do not state in what part of the state the disease was found. The fact, however, that the mean rainfall was taken for the state and that the observations on the disease were made in various parts of the state probably renders the data of more value than if taken for a limited section.

It will be seen from the summary of the observations on the occurrence of late blight included in the table, that the disease shows a tendency to appear in cycles. It was reported as being present in the years 1889 and 1897 inclusive, and absent the following four years; in 1897 it was again present and was unusually severe only to be absent in the following three

years. Similar instances of a tendency for the disease to appear in cycles are to be observed in the remaining years. In connection with this tendency it is advisable to consider the method whereby the fungus is perpetuated from year to year. The chief source of primary infection is the planting of seed tubers infected with the late blight organism. Should favorable meteorological conditions exist during the summer months the disease will probably gain a foot-hold and will result in the blighting of the vines and, with continued favoring conditions, the rotting of the tubers. In case a warm, dry season follows the planting of infected seed potatoes it is questionable if the disease would appear. It is not unreasonable to believe that seed potatoes carrying the late blight organism are planted every year in New Jersey and yet the records show that the trouble has been present in only eighteen of the past thirty-four years. This would indicate that the appearance of late blight is dependent on some factor other than the planting of diseased seed and the results of this study indicate that its occurrence is dependent on meteorological conditions. Evidence to support this is furnished as the result of observations made in 1920 and 1921. In south Jersey, in the fall of 1920, late blight was very severe on the late crop grown for seed. This seed, a large amount of it infected with late blight rot, was planted in the state in the spring of 1921 and a close examination failed to reveal any late blight on the 1921 crop. The weather records for this year show that it was one of the warmest and dryest in the past thirty-four years. Similar observations were made in Wisconsin by Jones (12) as the result of a critical study of late blight in the summers of 1915 and 1916. He states that, "of these two summer seasons, 1915 was cool and moist and 1916 exceptionally hot and dry. In 1915 the late blight fungus, stimulated by the favoring weather, destroyed some millions of dollars worth of potatoes with the worst outbreak in at least a decade. As a result, almost every lot of seed potatoes in the state carried the infection to the fields in 1916, yet the dry heat held the parasite so completely in check that the expert mycologist had to search the potato fields of the state with a magnifying glass to find a single incipient development of the disease."

The relation of rainfall to the occurrence of late blight is shown in table 1. In the first column of the table is given the year, in the next four columns the rainfall for the four months considered, while in the sixth column the total precipitation for the four months is shown. The figures given in italics indicate months when the rainfall was above the 34-year average for that month. A study of the sixth column of the table brings out the fact that, with but few exceptions, when the rainfall was above the average, late blight was reported as being present in the state and in most every instance, in those years when the rainfall was below the average, no late blight was present. Notable exceptions to this are apparent in the years 1896 and 1905 when, although the total rainfall was above the average there was no late blight. This may no doubt be explained by the fact that in 1896 the August rainfall was well below the average for the month and, as will be shown later, the July temperature was above the average. In 1905 the rainfall in July was below the average, and the temperature above the average for the month. In certain other years,

although the rainfall was below the average, late blight was reported and a study of these years shows that in certain months the rainfall was approximately equal to or above the average for the month. It is shown later that an excess of rainfall in some months is more likely to function in determining an outbreak of late blight than is an excess in other months and that total precipitation regarded in this connection is likely to be misleading.

TABLE 1

INFLUENCE OF RAINFALL ON LATE BLIGHT

YEAR	Mean Rainfall for New Jersey					PREVALENCE OF LATE BLIGHT
	June	July	Aug.	Sept.	Total	
	in.	in.	in.	in.	in.	
1889	**3.73**	**10.19**	**5.13**	**8.36**	**27.41**	Blight and rot unusually severe
1890	3.59	**5.62**	**4.90**	**4.75**	**17.86**	Blight and rot unusually severe
1891	2.92	**5.30**	**5.32**	2.46	16.00	Blight and rot especially on late potatoes
1892	**3.85**	4.03	3.63	1.81	13.32	Some blight on late potatoes
1893	2.95	2.72	**6.52**	3.20	15.39	None
1894	2.28	1.66	2.58	**7.46**	13.98	None
1895	3.24	4.26	2.53	1.07	11.10	None
1896	**5.46**	**5.50**	1.83	**4.37**	**17.16**	None
1897	3.38	**11.42**	4.39	1.65	**20.84**	Blight and rot unusually severe
1898	2.10	4.96	**5.36**	2.00	14.42	None
1899	2.50	**5.75**	4.36	**5.88**	16.49	None
1900	3.08	4.74	2.68	2.86	13.36	None
1901	1.57	**5.87**	**9.43**	3.38	**20.25**	Some rot
1902	**6.57**	4.78	3.91	**5.65**	**20.91**	Blight and rot reported
1903	**7.68**	**5.51**	**6.95**	3.34	**23.48**	Blight and rot severe
1904	3.13	4.87	**6.62**	**4.79**	**19.41**	Considerable rot
1905	3.43	4.06	**5.72**	**5.23**	**18.44**	None
1906	**4.48**	**5.58**	**5.95**	2.19	**18.10**	Blight, very little rot
1907	**4.41**	**6.62**	3.45	**8.08**	**22.56**	Blight and rot severe
1908	2.32	4.70	**5.05**	2.09	14.16	None
1909	3.26	2.12	4.59	3.30	13.27	None
1910	**5.17**	1.36	3.78	2.39	12.70	No record available
1911	**5.36**	3.64	**8.91**	2.88	**19.79**	No record available
1912	1.94	3.86	3.42	**4.47**	13.69	One report of blight
1913	1.80	2.52	4.06	**3.87**	12.25	None
1914	2.66	**6.05**	3.15	0.37	12.23	Blight severe
1915	3.12	**5.31**	**7.73**	2.08	**18.24**	Blight severe
1916	**4.20**	**5.40**	1.34	2.84	13.78	None
1917	**4.27**	4.83	2.21	2.74	14.05	None
1918	3.43	3.93	1.85	**3.84**	13.05	Some blight, very little rot
1919	3.16	**8.39**	**6.89**	3.26	**21.70**	Blight and rot severe
1920	**6.18**	**5.76**	**6.10**	**3.87**	**21.91**	Blight and rot severe
1921	3.23	3.62	4.32	2.35	13.52	None
1922	**6.31**	**5.79**	4.03	2.26	**18.39**	Blight and rot severe on early crop.
Average	3.73	5.02	4.67	3.56	16.86	

Bold face indicate months when the rainfall was above the 34-year average for that month.

The relation of precipitation in the various months to outbreaks of late blight is shown in table 2. In the table each of the four months considered in the 34 years is divided into two groups. The first group includes all months in which the rainfall was above the 34-year average for the month in question, while the second group includes the months when the rainfall was below the average. Each of these two groups are then subdivided into years of blight and those of no blight.

From the table it will be seen that when the rainfall is above the average, the month of July apparently has a greater influence in determining the presence of late blight than any of the other months and has approx-

imately the same effect as July and August; July, August and September; and June, July, August and September combined. There were sixteen years when the rainfall in July was above the average and in these years late blight was present thirteen years and absent three years. On the other hand in the sixteen years when the rainfall of July was below the average there were five years of blight and eleven years of no blight. As will be shown later, in most cases when late blight was reported in years when the month of July was dry,the disease was confined to the foliage and little rot was experienced. The figures included in this section of the table indicate that when the rainfall of the various months was below average the limiting influence of July is more apparent than that of any of the other months and has about the same value as a combination of the different months. In other words, the accumulative effects of dry weather in July and August, July, August and September or June, July, August or September have but little more influence on preventing the appearance of late blight than has dry weather in July alone.

TABLE 2

Influence of Precipitation in Various Months on Late Blight—1889-1922*

PERIOD	Rainfall above Average					Rainfall below Average				
	No. of Years	Years of Blight		Years of no Blight		No. of Years	Years of Blight		Years of no Blight	
		No.	Per Cent	No.	Per Cent		No.	Per Cent	No.	Per Cent
June	10	7	70.0	3	30.0	22	11	50.0	11	50.0
July	16	13	81.2	3	18.8	16	5	31.2	11	68.8
August	14	10	71.4	4	28.6	18	8	44.4	10	55.6
September	13	8	61.5	5	38.5	19	10	52.6	9	47.4
July and August	15	13	86.6	2	13.4	17	5	29.4	12	70.6
July, Aug. and September	14	12	85.7	2	14.3	18	6	33.3	12	66.7
July, Aug., Sept. and Oct.	15	13	86.6	2	13.4	17	5	29.4	12	70.6

*Years 1910 and 1911 not included.

Influence of Temperature on Late Blight

In table 3 is shown the temperature for the months of June, July, August and September as well as the average temperature for the four months in each year since 1889. As was the case with the precipitation records, the temperature records given represent the mean for the state. The figures in italics represent months when the temperature was below the 34-year average for the month. It will be observed from the last column of the table that in most cases, when the average temperature for the four months was below the 34-year average, late blight was reported as being present in the state in most every instance. Exceptions to this appear, however, in the years 1893, 1905, 1909, 1913, 1916 and 1917. The failure of the disease to appear in 1893, 1905, 1909 and 1913 may be accounted for by the fact that the rainfall in the month of July in these years was considerably below the average for the month. In 1916 and 1917, while the temperature in certain individual months was sufficiently low

to result in an average temperature below the 34-year average, the temperature for the month of July in the years in question ranged from 73.9 to 74.4, slightly higher than the average for this month. In 1891, 1906 and 1922, while the temperature was above the average, late blight was reported, but it will be observed that in these years the temperature of the month of July was equal to or below the average for the month and in addition, the rainfall in July was above the monthly average.

TABLE 3

INFLUENCE OF TEMPERATURE ON LATE BLIGHT

YEAR	Mean Temperature for N. J.					PREVALENCE OF LATE BLIGHT
	June	July	Aug.	Sept.	Average	
	°F.	°F.	°F.	°F.	°F.	
1889	69.9	***73.4**	**69.6**	**64.8**	**69.4**	Blight and rot unusually severe
1890	70.7	**72.5**	**71.5**	**64.4**	**69.8**	Blight and rot unusually severe
1891	69.7	**70.1**	72.8	68.7	70.3	Blight and rot, especially on late potatoes
1892	72.4	74.3	73.4	**64.2**	71.1	Some blight on late potatoes
1893	69.7	73.9	72.8	**62.7**	**69.8**	None
1894	70.6	75.7	**70.9**	68.8	71.5	None
1895	71.7	**70.9**	74.2	69.7	71.6	None
1896	***68.1**	75.0	73.6	**65.1**	70.4	None
1897	**66.1**	74.1	**71.0**	**65.5**	**69.2**	Blight and rot unusually severe
1898	70.1	75.3	74.8	68.6	72.2	None
1899	72.3	74.7	72.3	**64.4**	70.9	None
1900	70.4	75.9	76.3	69.9	73.1	None
1901	70.0	77.3	73.8	66.8	72.0	Some rot
1902	**67.5**	**73.0**	**70.1**	**64.6**	**68.8**	Blight and rot reported
1903	**64.0**	**73.3**	**68.4**	**65.0**	**67.7**	Blight and rot severe
1904	**68.6**	**72.3**	**70.8**	**64.8**	**69.1**	Considerable rot
1905	**68.3**	74.4	**71.1**	**65.4**	**69.8**	None
1906	70.4	**72.8**	74.6	68.9	71.7	Blight, very little rot
1907	**64.7**	**73.6**	**70.5**	67.1	**69.0**	Blight and rot severe
1908	69.9	75.6	**70.6**	**65.7**	70.4	None
1909	70.0	**71.6**	**70.2**	**64.5**	**69.1**	None
1910	**66.9**	75.3	**70.4**	67.3	**70.0**	No record available
1911	**68.9**	76.0	72.1	66.4	70.8	No record available
1912	**68.0**	**73.7**	**70.0**	**65.9**	71.9	One report of blight
1913	69.1	74.4	**71.7**	**64.4**	**69.9**	None
1914	**68.5**	**71.5**	73.3	**64.0**	**69.3**	Blight severe
1915	**67.0**	**72.8**	**70.9**	68.5	**69.8**	Blight severe
1916	**64.7**	74.4	73.2	**65.2**	**69.4**	None
1917	**68.9**	74.2	74.0	**61.5**	**69.6**	None
1918	**66.3**	**72.2**	74.4	**62.2**	**68.8**	Some blight, very little rot
1919	69.5	**73.5**	**69.9**	**65.8**	**69.7**	Blight and rot severe
1920	**68.4**	**71.7**	72.3	66.8	**69.8**	Blight and rot severe
1921	70.4	76.5	**69.8**	70.2	71.7	None
1922	71.1	**73.0**	**71.2**	66.7	70.5	Blight and rot severe on early crop
Average	68.9	73.7	72.2	66.0	70.2	

Bold face indicate months when the temperature was below the 34-year average for that month.

In this connection it is necessary to examine the influence of temperature of individual months on the occurrence of the late blight. This is shown in the figures of table 4. The arrangement of the table is the same as that showing the influence of precipitation in various months. It will be seen from the table that in the eighteen years when the temperature of June was above the average there were eight years of blight and ten of none. In the fourteen years when the June temperature was below the average there were ten years of blight and four years of none.

The records for the months of August and September are not far different from those for June. When, however, the data for July is exam-

ined the situation is quite different, indicating the importance of the temperature relations in this month on the appearance of the disease. In the thirty-two years under consideration there were fifteen when the July temperature was above the average for the month. In these fifteen years there were only three when blight was recorded and in these years it was not severe. On the other hand there were seventeen years when the July temperature was below the average and in this time there were fifteen years when blight was present and in most cases the trouble was severe.

TABLE 4

Influence of Temperature in Various Months on Late Blight—1889-1922*

PERIOD	Temperature above Average					Temperature below Average				
	No. of years	Years of Blight		Years of no Blight		No. of years	Years of Blight		Years of no Blight	
		No.	Per Cent	No.	Per Cent		No.	Per Cent	No.	Per Cent
June	18	8	44.4	10	55.6	14	10	71.4	4	28.6
July	15	3	20.0	12	80.0	17	15	88.2	2	11.8
August	15	7	46.7	8	53.3	17	11	64.7	6	35.3
September	12	7	58.3	5	41.7	20	11	55.0	9	45.0
July and Aug.	16	4	25.0	12	75.0	16	14	87.5	2	12.5
July, Aug. and Sept.	14	5	35.7	9	64.3	18	13	72.2	5	27.8
June, July, Aug. and Sept.	14	6	42.9	8	57.1	18	12	66.7	6	33.3

*Years 1910 and 1911 not included.

The data included in table 4 thus indicates that while cool weather in June, July or August is generally more favorable than is warm weather for the development of late blight, the temperature of June or August alone is of less importance than is that of July. In addition it shows that the combined temperature of July and August; July, August and September; or June, July, August and September, is of less importance than is the temperature of July alone in determining outbreaks of late blight.

Influence of Sunshine

In view of the fact that the study of the influence of rainfall and temperature in the various months indicates that the weather conditions of July and August are more intimately concerned with outbreaks of late blight than are those of June and September, the study of the influence of sunshine has been restricted to these two months. The same method was followed in studying this factor as was adopted for the other two factors. The data shows that in eighteen years the percentage of sunshine in the month of July was above the average and in this time there were six years with blight and twelve years without blight. In the remaining fourteen years, when the amount of sunshine was below the average there were eleven years with blight and three years with none.

It was found that there was a very close agreement between the years of high rainfall and cloudy days, rendering it impossible to make any definite statement as to the possible influence of sunshine or cloudy weather on late blight. There is no question, however, but that sunshine indi-

rectly is important since it unquestionably limits the effect of an excess of moisture. Even under conditions of heavy rainfall, if there is sufficient sunshine the moisture would soon be evaporated and it is doubtful if under conditions of this kind late blight would prove to be serious.

In determining the influence of sunshine in the months of July and August it was found that lack of sunshine in the month of July was more important in determining an outbreak of late blight than a similar condition in August or in July and August combined.

Combined Influence of Rainfall and Temperature

While both rainfall and temperature are unquestionably important factors in determining an outbreak of late blight, the influence of one is modified by the other. The combined influence of rainfall and temperature in the various months is shown in table 5. The first column of this

TABLE 5

COMBINED INFLUENCE OF TEMPERATURE AND RAINFALL ON LATE BLIGHT

PERIOD	Warm and Wet		Warm and Dry		Cool and Wet		Cool and Dry	
	Blight	No Blight	Blight	No Blight	Blight	No Blight	Blight	No Blight
	Years	Years	Years	Years	Years	Years	Years	Years
June	4	0	4	8	4	3	6	3
July	2	3	1	9	11	0	4	2
August	4	2	3	6	6	2	5	4
September	2	1	5	4	6	4	5	5
July and August	2	4	2	8	11	0	2	3
July, Aug. and Sept.	3	1	2	7	9	1	4	5
June, July, Aug. and Sept.	3	1	3	7	10	1	2	5

table gives the period, in the remaining columns is given the number of years of blight and of no blight for the weather conditions indicated. There were four years, for example, when the month of June was warm and wet, i. e. the temperature and rainfall were both above the mean for the month. In each of these four years blight was recorded. Likewise there were twelve years when June was warm and dry, i. e. the temperature above and the rainfall below the average. In these twelve years, there were four years of blight and eight years of none. Similar records are indicated for the June months that were cool and wet and for those that were cool and dry. The data for the other months is expressed in a similar manner.

It is apparent from the table that in any of the months the influence of the two factors considered, either alone or in combination with each other has less weight than in July alone. In five years when July was warm and wet there were two years of blight and three years of none. In ten years when July was warm and dry there was one year when a trace of blight was reported and nine years of none. July was cool and wet eleven years and during this time blight was present every year, while in

the six years when this month was cool and dry there were four years of blight and two years of none. In other words, when the temperature of July was between 70.1°F. and 73.6°F. and the rainfall between 5.30 and 10.19 inches late blight was present every year, in the ten years when the temperature ranged from 73.9° to 76.5° and the rainfall from 1.66 to 4.96 inches the disease was reported only once. With a temperature of 72.2° to 73.7° and rainfall from 2.12 to 4.86 inches the trouble was experienced four years out of six while with a temperature of 74.1° to 77.3° and a rainfall of 5.40 to 11.42 inches blight has been present two years out of five.

The influence of these two factors is clearly shown in the chart in figure 1. In this chart the heavy perpendicular line indicates the average temperature for the month of July over a 34-year period. The lines to the right and left of this line indicate degrees of temperature above and below the average respectively. The heavy horizontal line indicates the average rainfall for the same period and the lighter lines above and below indicate departures from the average. The intersection of any of these lines indicates departures from the average rainfall and temperature for any July in the thirty-two years under consideration (1910 and 1911 not included). In plotting the rainfall and temperature for any particular July a symbol is placed to indicate the presence or absence of blight in that year. If there was no blight a circle was drawn, if blight was recorded as being present, but not severe, a cross was placed in the circle, while if blight was severe the circle was filled in.

This chart shows that when July is cool and wet late blight can be expected and conversely when warm and dry it will seldom appear. An interesting relationship brought out in the chart is the influence of cool and dry weather as compared with warm and wet weather on the prevalence of late blight. In the six years when July was cool and dry there were four years of blight and two years of none. On the other hand in the five years when July was warm and wet, blight was present in two years and absent in three. In one of the two years there was only a slight amount of blight, while in the other, although blight was severe, the temperature for the year was only slightly above normal while the rainfall was the heaviest in the thirty-four years. The data clearly indicate that while rainfall is important in determining an outbreak of late blight its influence is modified to a marked extent by temperature.

The combined influence of rainfall and temperature upon the prevalence of late blight may be brought out in another way. The rainfall for the month of July in each year was plotted to form the graph shown in figure 2. Here the abscissas are taken arbitrarily to represent the different years, which are indicated at the bottom of the graph and the ordinates represent the rainfall in inches. With the same ordinates the July temperature for the corresponding years is plotted in degrees fahrenheit. The heavy horizontal line represents the mean rainfall and temperature for the month. From figure 2 it is at once clear that in those years when the July rainfall was above 4.74 inches, late blight was present in almost every instance. Notable exceptions are to be observed, however, in the years 1899, 1896, 1916, 1898 and 1917. From the graph it will be observed that

in each of these years the temperature was above the average. The limiting effect of temperature is likewise apparent in 1901, when, although this was one of the wettest of the thirty-four years the outbreak of late

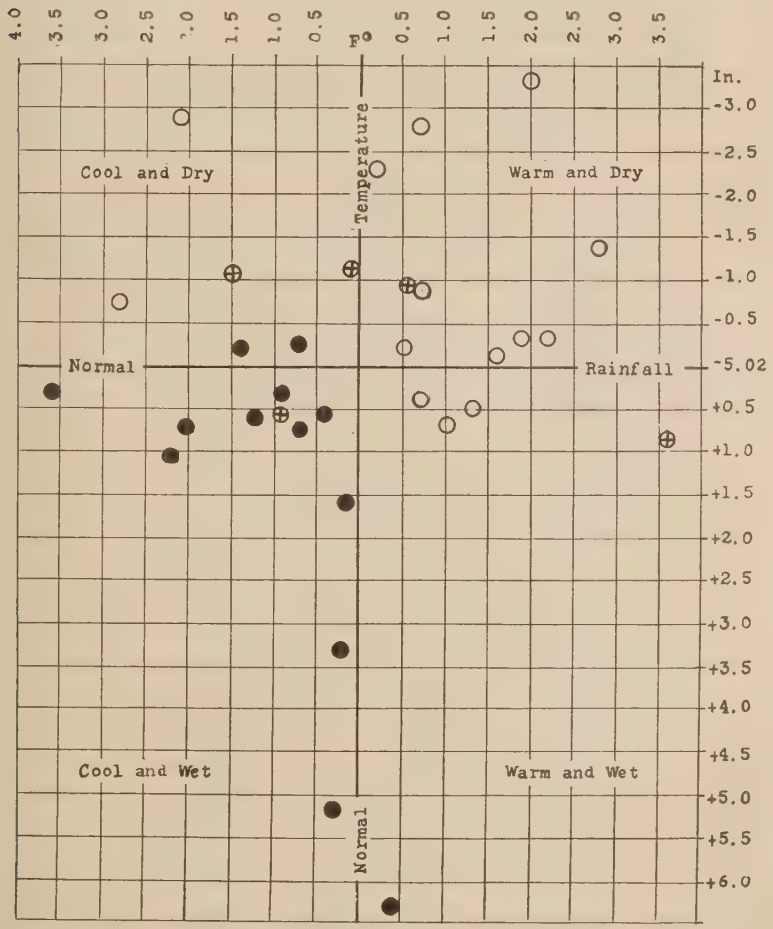

FIG. 1. COMBINED INFLUENCE OF TEMPERATURE AND RAINFALL IN THE MONTH OF JULY ON LATE BLIGHT. BLACK DOTS—SEVERE BLIGHT. CIRCLE WITH CROSS—SLIGHT BLIGHT. CIRCLE—NO BLIGHT.

blight was very slight, due probably to the very high temperature that existed during July of that year.

It will be observed from the graph that in three years when the rainfall was well below the average, late blight was reported. An examina-

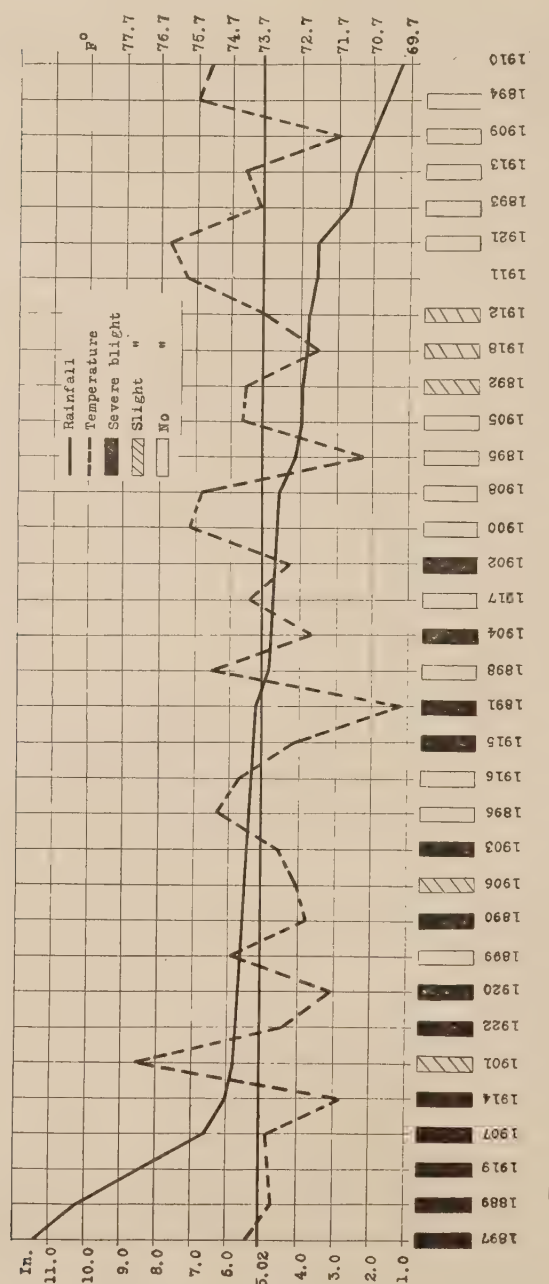

Fig. 2. Curve Showing Relation of Temperature and Rainfall to Occurrence of Late Blight, 1889-1922.

tion of the original records indicates that the trouble in these years was not severe. In 1892 it was confined to the late crop; in 1918, while there was considerable blight reported from central New Jersey, rot was not severe; in 1912 there was only one report of the disease from the state. No records are available for 1910 and 1911. In a communication from L. R. Haskell of the Plant Disease Survey, he states that during these two years the disease was probably less prevalent over the country as a whole than during any time in the past twenty years. In view of this fact and the very low rainfall for the month of July in these two years it is questionable if blight was present in the state.

Summary

1. Late blight potatoes, caused by the fungus *Phytophthora infestans* was first reported in New Jersey in 1889 and since that time the disease has been reported as being present in eighteen years.

2. Results of a correlation of weather conditions with outbreaks of late blight indicate a close relationship between the two. In 34 years the combined rainfall for the months of June, July, August and September was above the average in sixteen years and in this time there were thirteen years when blight was reported. During this same period there were eighteen years when the temperature for the four months was below the thirty-four year average. In this time blight was reported as being present in twelve and absent in six years. A similar correlation of the prevalence of late blight with cloudy weather shows that when the months of July and August are considered, there were thirteen years when the per cent of sunshine was below the average and in this time the trouble was reported as being present nine and absent four years.

3. While rainfall and temperature are important factors in determining an outbreak of late blight, the influence of one is limited by the other. A correlation of the combined influence of temperature and rainfall with the prevalence of blight indicates that the influence of these two factors in the months of June, August or September, either alone or in combination with each other, has less weight in determining an outbreak of late blight than has a combination of the same factors in the month of July alone.

4. In those years when the July temperature was below the average (73.7°F.) for the month and the rainfall above the average, (5.02 in.) epidemics of late blight were experienced every year. With approximately the same rainfall range but with the temperature above the average the disease was reported in two years out of five, in one of the two years only one report of late blight was recorded, and, while the disease was severe in the other, the temperature in that year was only slightly above the average and the rainfall was the heaviest of the thirty-four years considered.

In those years when the July temperature was above and the rainfall below the average for the month, late blight was experienced in only one year out of 10; however, in the years when the month of July showed approximately the same rainfall but with the temperature below the average, blight was reported as being present in four years out of six.

5. The rainfall in the month of July was greater than 4.74 inches in twenty years and during this time late blight was present in every year but five. In these five years the temperature for the month was above the average; indicating that while rainfall is a factor of considerable importance in determining outbreaks of late blight, its influence is limited to a marked extent by the existing temperature.

6. In New Jersey when the temperature for the month of July is below 74°F. and the rainfall above 4.74 inches, conditions are produced that are likely to result in an epidemic of late blight.

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